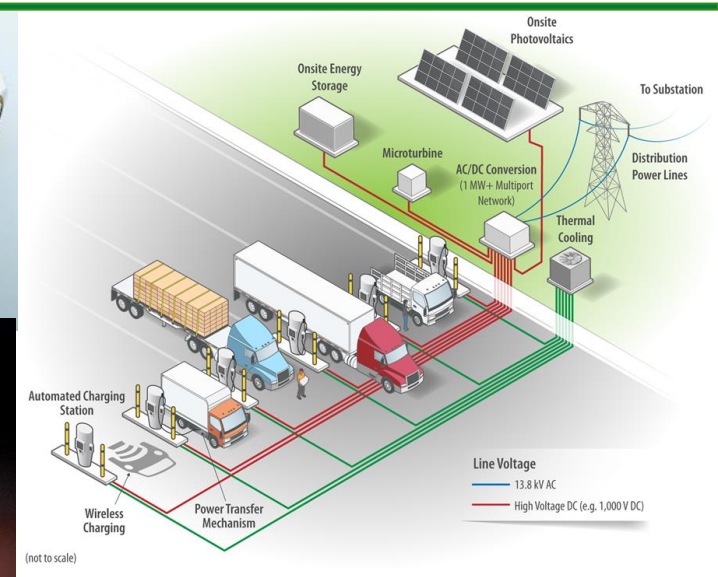
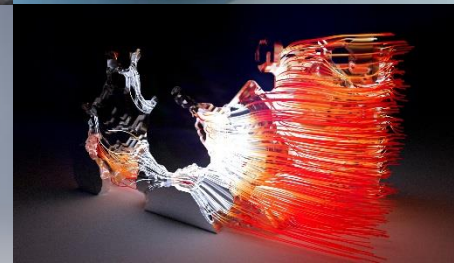
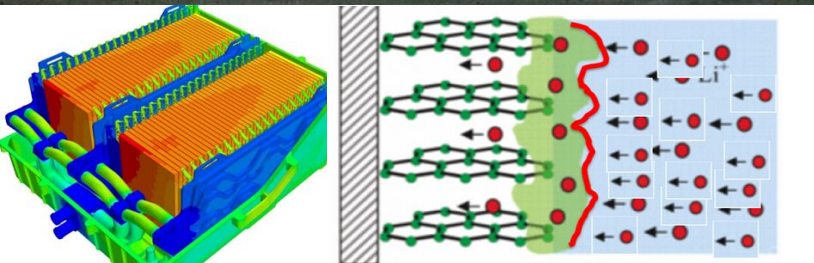


# Vehicle Technologies Office Battery R&D Overview

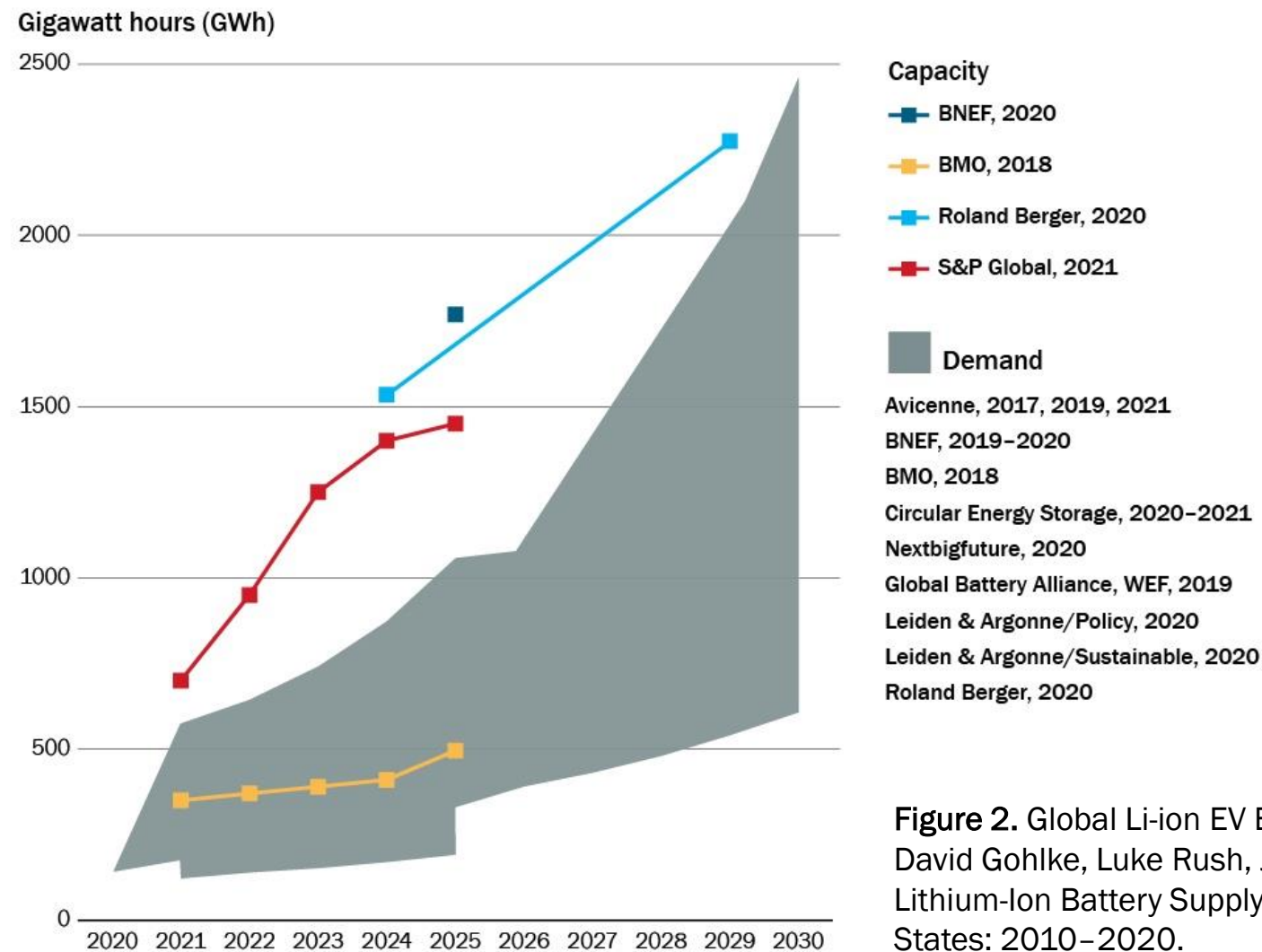
## *ARPA-E High Energy, Fast Charging Batteries for EV Applications Workshop*

David Howell  
Vehicle Technologies Office

*October 26, 2021*



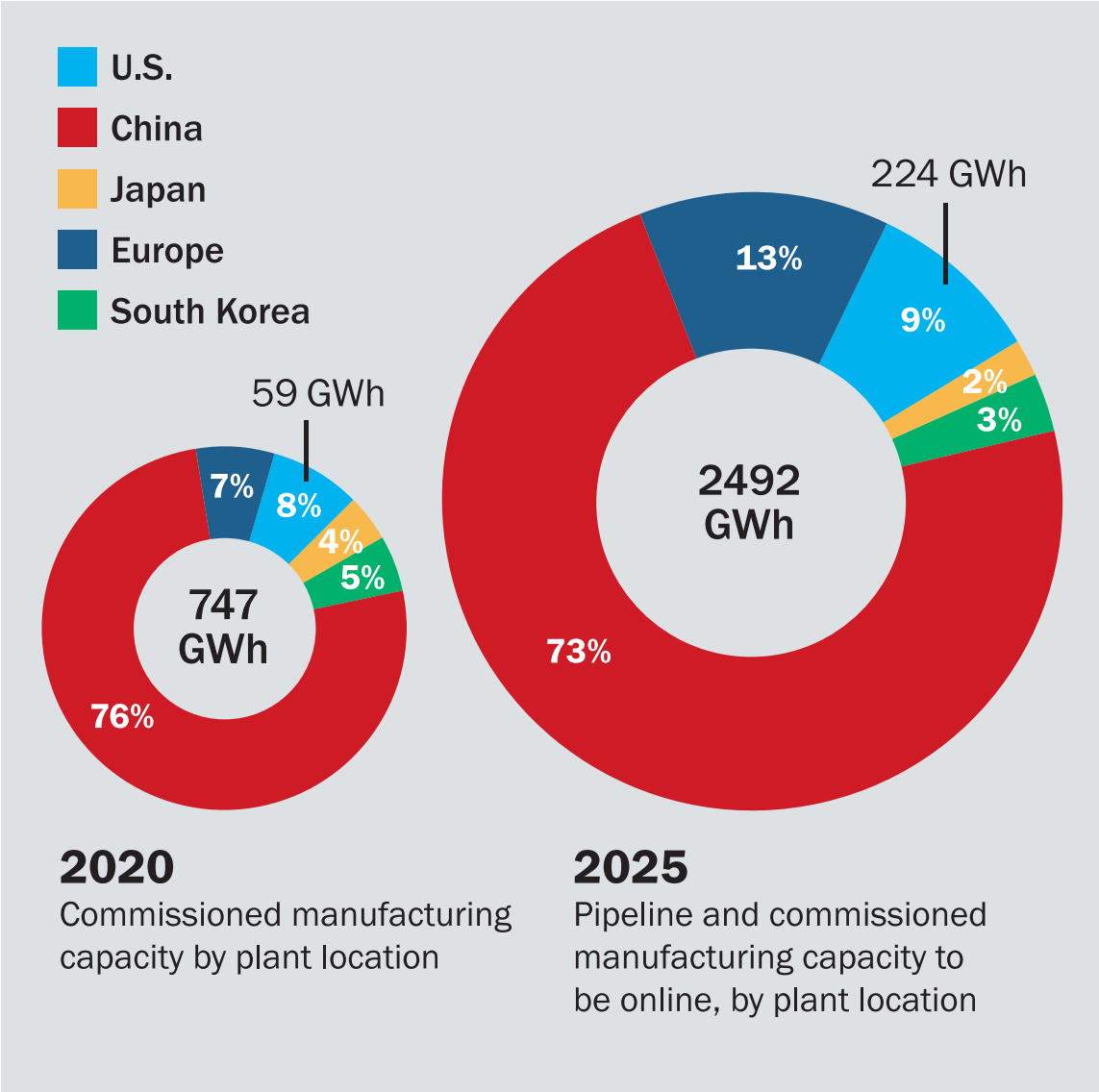
# Global Expansion of Lithium Battery Demand and Manufacturing Capacity is Projected



- Numerous projections indicate a significant acceleration of lithium battery demand and production capacity over the next decade.
- The more recent projections indicate the most rapid acceleration.

**Figure 2.** Global Li-ion EV Battery Demand Projections. Yan Zhou, David Gohlke, Luke Rush, Jarod Kelly, and Qiang Dai (2021) Lithium-Ion Battery Supply Chain for E-Drive Vehicles in the United States: 2010–2020.  
Source: Argonne National Laboratory ANL/ESD-21/3.

# Global Expansion of Lithium Battery Manufacturing is already Occurring



- Lithium-ion battery cell production already poised to significantly expand by 2025
- A ~4X increase in the U.S.

**Figure 3.** Cell manufacturing capacities.  
Source: “Lithium-Ion Battery Megafactory Assessment”, Benchmark Mineral Intelligence, March 2021.

# National Blueprint for Lithium Batteries

By 2030, the United States and its partners will establish a secure battery materials and technology supply chain that supports long-term U.S. economic competitiveness and job creation, enables decarbonization goals, and meets national security requirements.



Minerals

Battery Materials

Cells/Packs

Recycling

Innovation

## GOALS TO ACHIEVE OUR VISION



**1** Secure access to raw and refined materials and discover alternates for critical minerals for commercial and defense applications



**2** Support the growth of a U.S. materials processing base able to meet domestic battery manufacturing demand



**3** Stimulate the U.S. electrode, cell, and pack manufacturing sector



**4** Enable U.S. end of life reuse and critical materials recycling at scale and a full competitive value chain in the United States



**5** Maintain and advance U.S. battery technology leadership by strongly supporting scientific R&D, STEM education, and workforce development



# DOE Battery R&D

## Basic Energy Sciences (BES)

Fundamental research to understand, predict, and control the interactions of matter and energy at the electronic, atomic, and molecular levels to enable revolutionary energy storage technologies

### Vehicle Technologies Office (VTO)

Battery R&D for Electric Vehicles

- lithium ion
- lithium metal/lithium sulfur
- solid state materials

### Office of Electricity (OE)

Energy Storage R&D for Stationary/Grid

- battery systems (lithium, sodium, etc)
- flow batteries
- other long duration storage

### Advanced Projects Research Agency–Energy (ARPA-E)

“Off-roadmap” Transformational R&D

## Advanced Manufacturing Office (AMO)

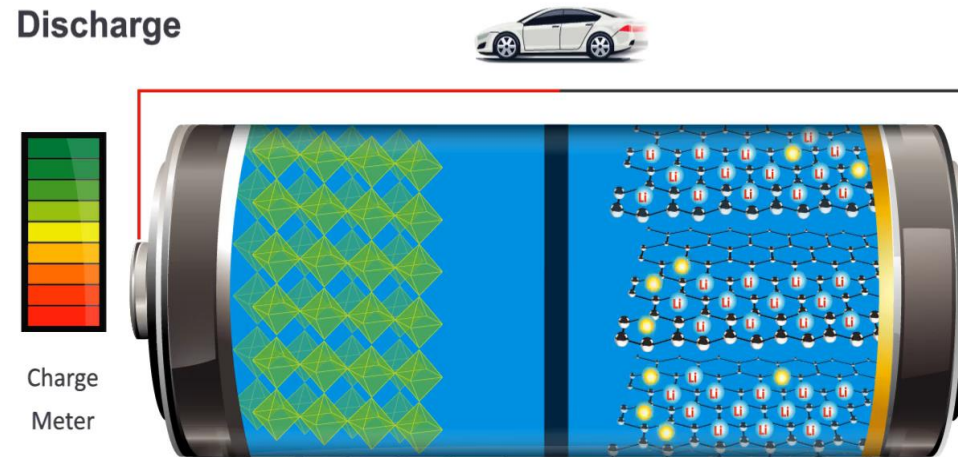
Support innovative manufacturing technology R&D focused on significantly reducing battery and energy storage cost, energy, emissions, and improve performance

# Electric Vehicle Battery R&D

## THREE MAJOR CHALLENGES

1. Further reduce battery costs (\$60/kWh cell)
2. Eliminate dependence on critical materials through material substitutes and/or recycling
3. Develop safe batteries that charge in <15 minutes

## How Lithium-ion Batteries Work



**Low or No  
Cobalt  
Cathodes**

**New Liquid  
Electrolytes  
or  
Solid State  
Materials**

**Silicon  
or  
Lithium Metal  
Anodes**

# DOE VTO Battery R&D: Near, Next, and Long Term

## Enhanced Li-ion (2020-2025) Graphite/NMC

Projected Cell Specific Energy and Cost  
300Wh/kg, \$90-100/kWh

|                         |            |
|-------------------------|------------|
| Current cycle life      | > 1000     |
| Calendar life           | > 10 years |
| Mature Manufacturing    | Yes        |
| Fast charge             | limited    |
| Cost positive recycling | No         |

### R&D Needs

- Fast charge
- Low temperature performance
- Low/no cobalt cathodes
- Cost positive recycling

## Next Gen Li-ion (2025-2030) Silicon/NMC (below 5wt%)

Projected Cell Specific Energy and Cost  
400Wh/kg, ~\$75/kWh

|                         |          |
|-------------------------|----------|
| Current cycle life      | > 1000   |
| Calendar life           | ~3 years |
| Mature Manufacturing    | limited  |
| Fast charge             | limited  |
| Cost positive recycling | No       |

### R&D Needs

- Enhanced calendar life
- Abuse tolerance improvement
- Low/no cobalt cathodes
- Cost effective and scalable pre-lithiation

## Lithium Metal (2025-2030) Li metal/DRX, Sulfur, other

Projected Cell Specific Energy and Cost  
500Wh/kg, ~\$50-60/kWh

|                         |       |
|-------------------------|-------|
| Current cycle life      | > 500 |
| Calendar life           | ???   |
| Mature Manufacturing    | No    |
| Fast charge             | No    |
| Cost positive recycling | No    |

### R&D Needs

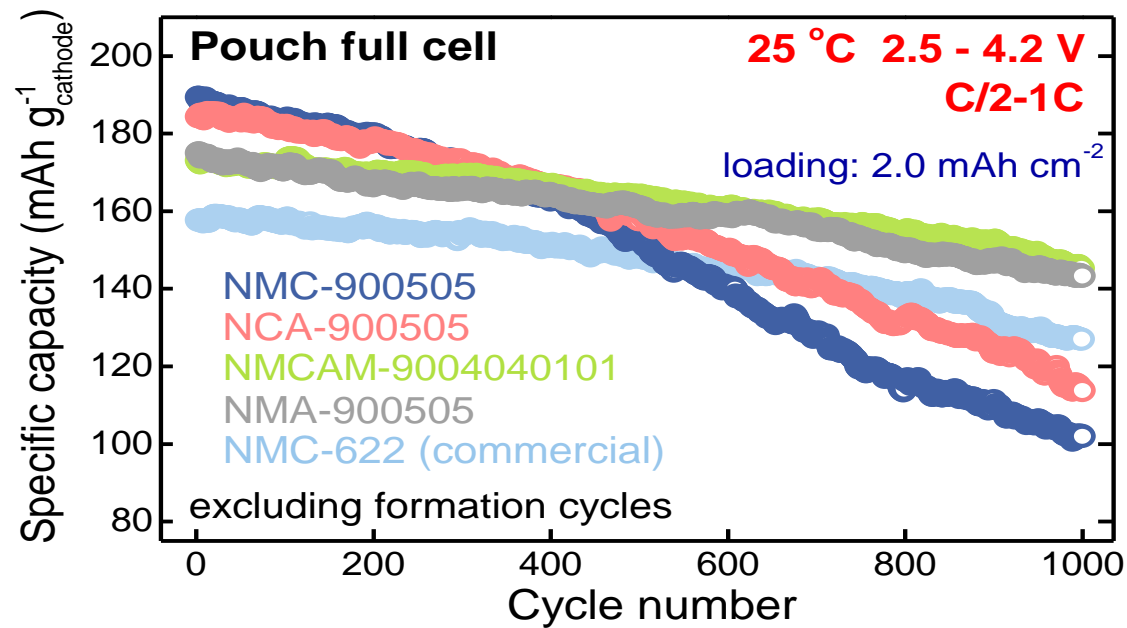
- Enhanced cycle and calendar life
- Protected lithium
- Dendrite detection and mitigation
- Cost effective manufacturing
- High conductivity solid electrolyte

# Low/No Cobalt R&D

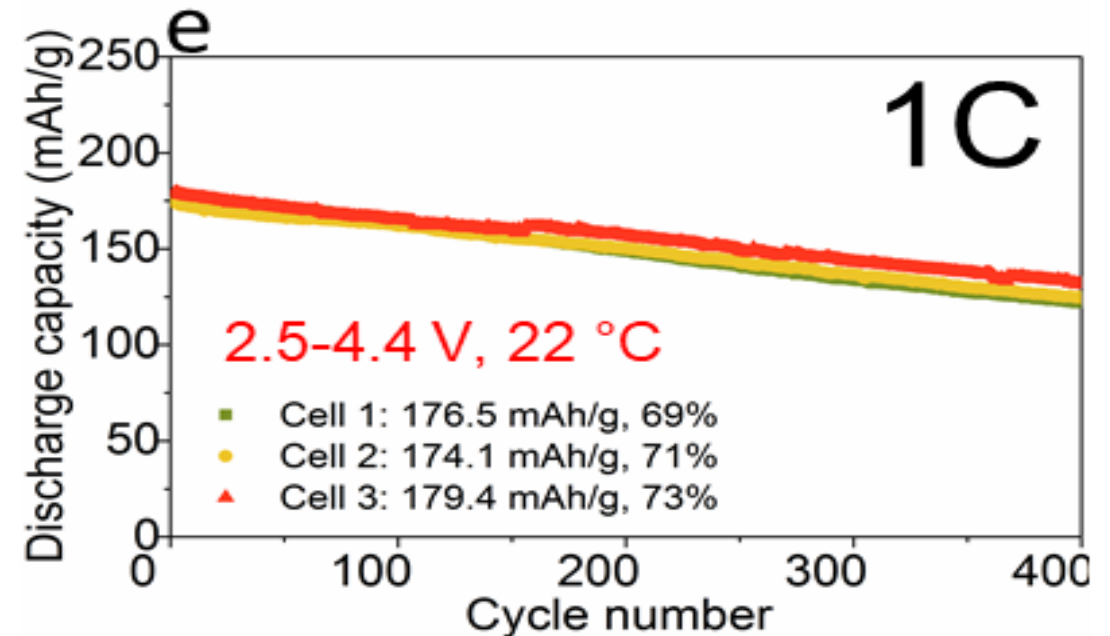
Cobalt and nickel are essential to today's Lithium-ion batteries and are critical materials

- The main chemistries under research high nickel NMC cathodes (Ni > 80%) and Cobalt free materials like the 5 Volt spinel,  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$

UT-Austin/NREL/Tesla (NMCAM and NMA)



UC-Irvine/VA-Tech high-Ni ( $\text{LiNi}_{0.96}\text{Ti}_{0.02}\text{Mg}_{0.02}\text{O}_2$ ).





# Silicon Anodes

## Opportunity

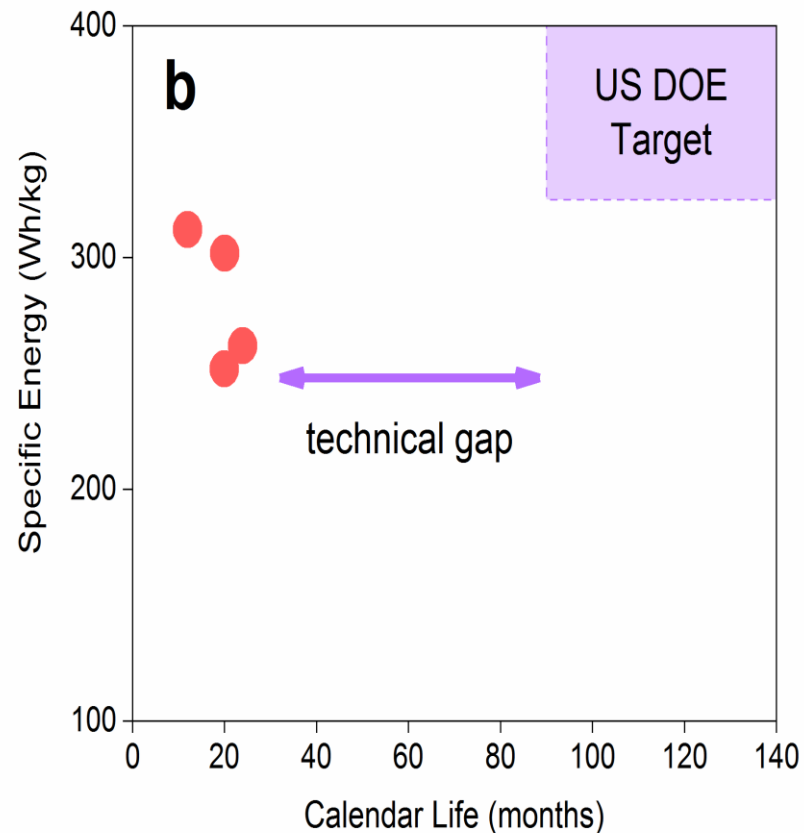
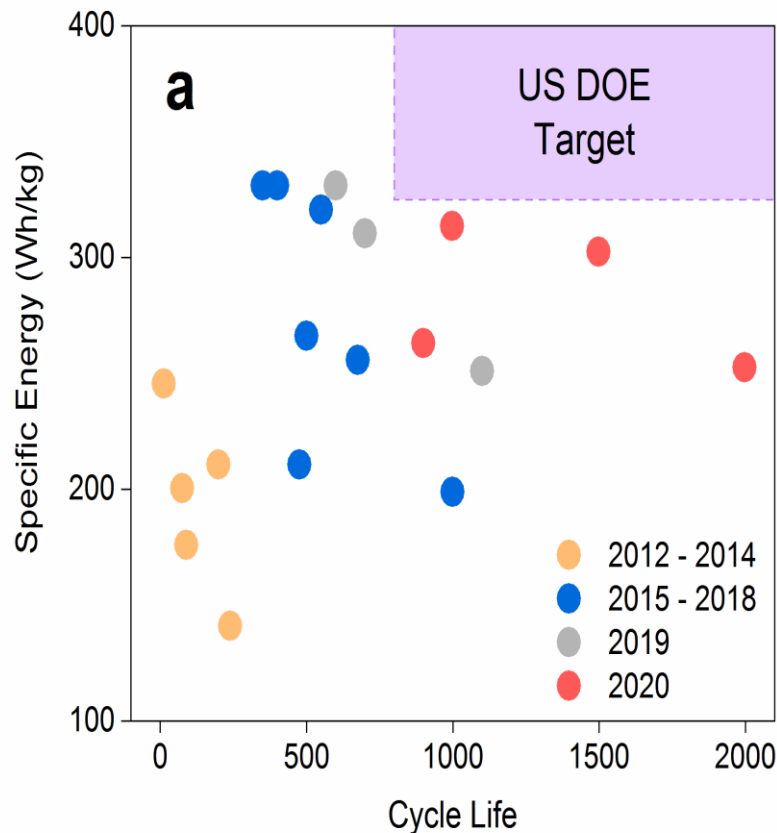
- Lower cost, volume, weight
- Earth Abundant Minerals
- Enable fast charge

## Targets

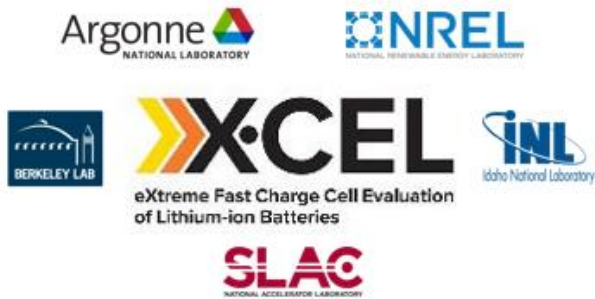
- 375 Wh/kg
- 1,200+ mAh/g (~3X)
- 1000 cycles, 10+ years

## Challenges

- First-cycle irreversible capacity loss
- Capacity fade: calendar life/cycle life
- High temperature thermal runaway



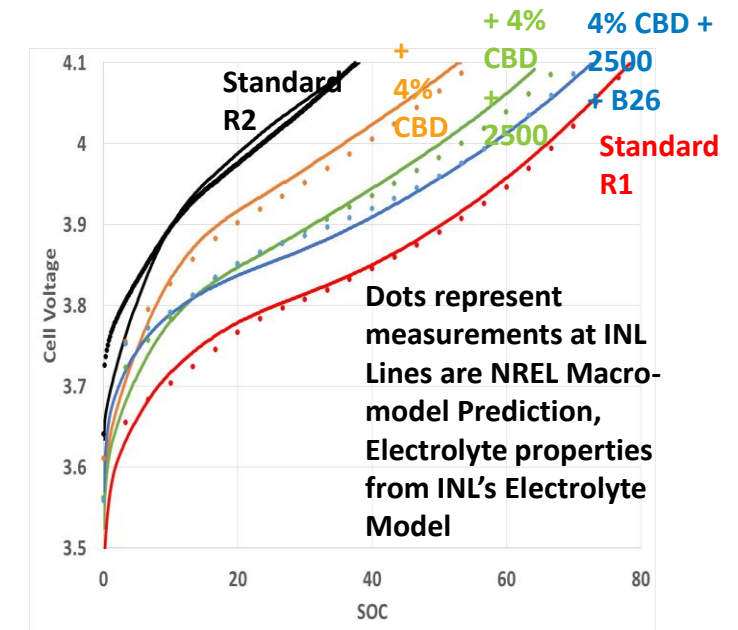
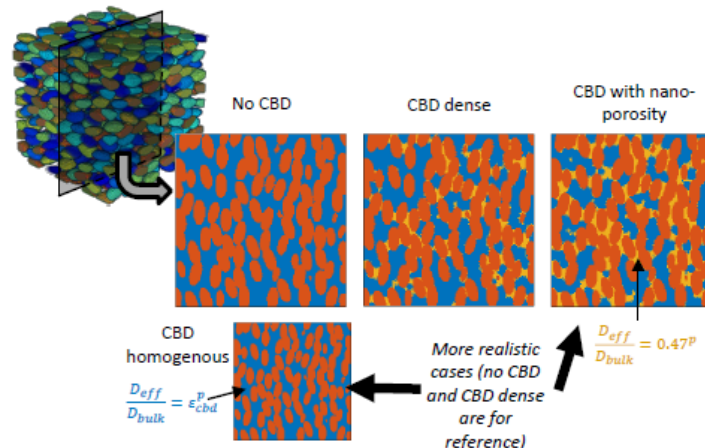
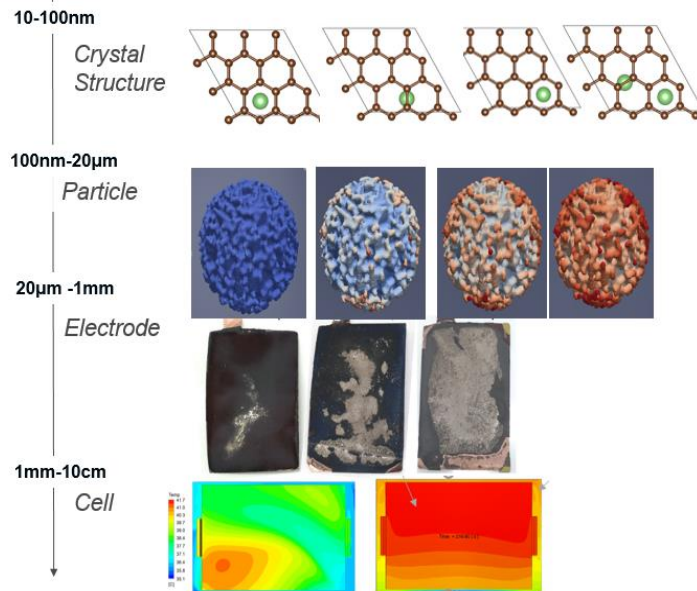
# Extreme Fast Charging (XFC)



Enable fast charging (10 minutes or less) of high-capacity batteries (above 200Wh/kg) while minimizing life impacts.

- Developing a fundamental understanding of the complex multivariable interactions at different length scales
- Exploring novel electrode designs with state-of-the-art materials
- Charge rate optimization

length scale



# Lithium Metal Progress – Battery500



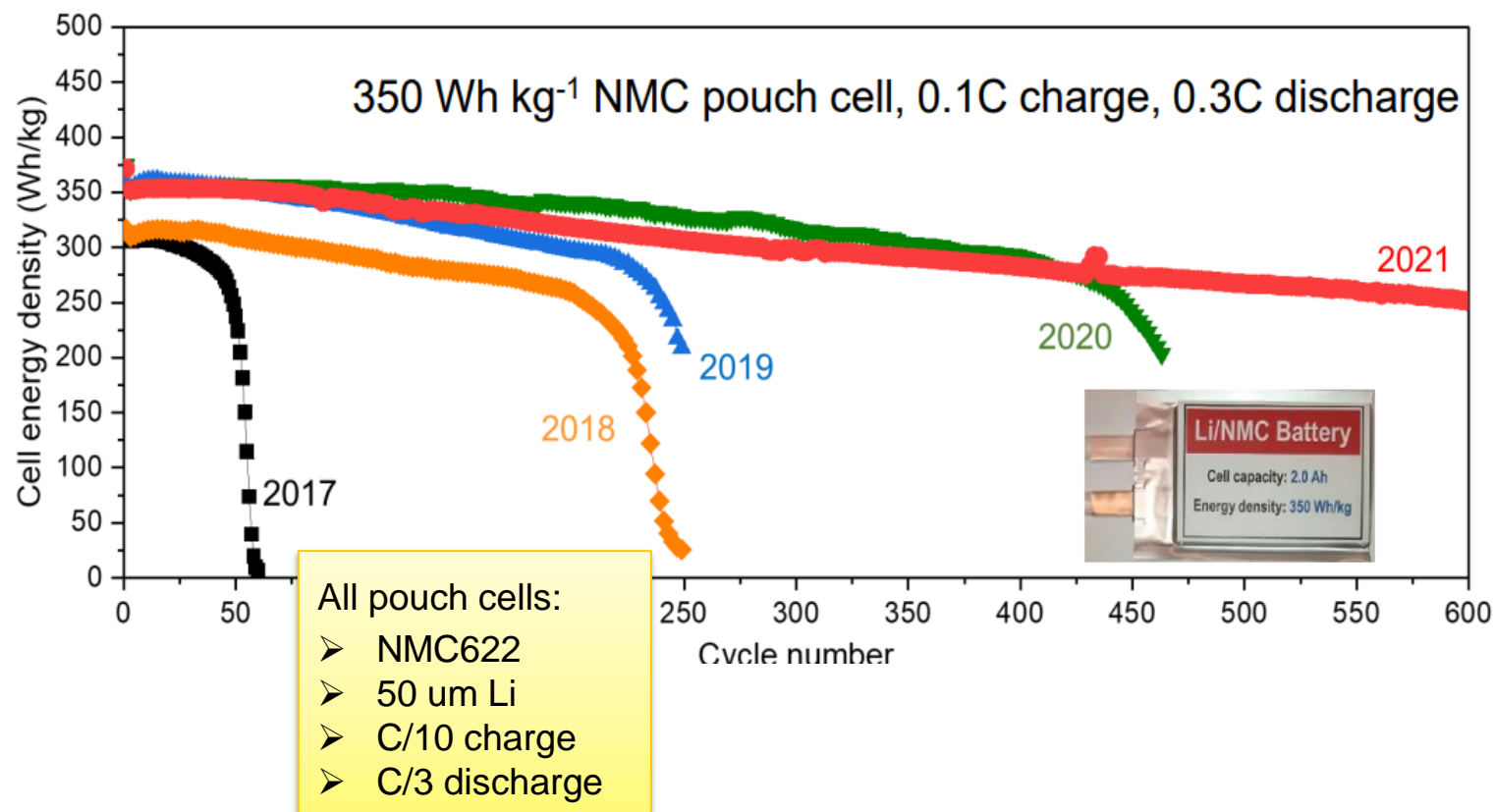
## National Labs



## Universities



- An integration of innovations developed by the consortium
  - Localized concentrated electrolyte: better SEI, decelerated side reactions
  - Electrode architecture: accelerate mass transport, fast ion diffusion
  - Cell design and balance: identify the rate-limiting step and improve

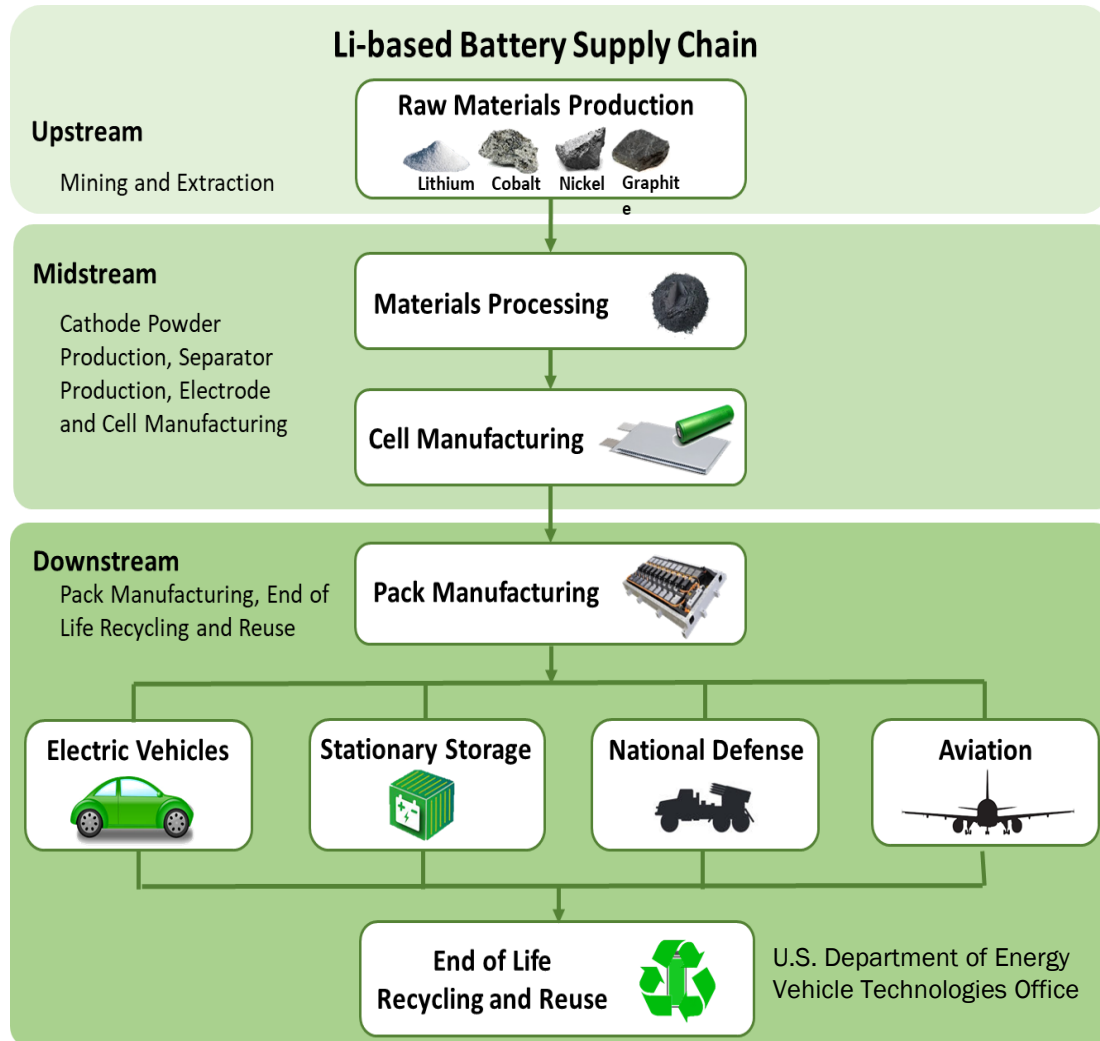


# Solid-State Electrolytes Under Investigation for Transportation Applications

## Potential Technology Advantages

- Non-combustible electrolyte leading to improved safety, and thermal management and packaging advantages
- Enables thinner electrodes, including lithium metal, leading to higher volumetric energy density
- Potential Bi-Polar cell design leading to higher voltages and improved volumetric energy density
- Reduced Cost

| Representative:                                | Polymers                       | Oxides                                  | Sulfides  |
|--|--------------------------------|---|---|
|  | PEO                            | LLZO                                    | Li <sub>2</sub> S - nP <sub>2</sub> S <sub>5</sub> Blends |
| Material Phase                                 | Amorphous                      | Crystalline                             | Crystalline or Glass                                      |
| Ionic Conductivity                             | Poor                           | Fair                                    | Good  |
| Air Stability                                  | Good                           | Good                                    | Poor  |
| Stability against Li Anode                     | Good                           | Good                                    | Poor  |
| Stability against High V Cathode               | Fair                           | Good                                    | Poor  |
| Ease of Manufacturing/<br>Processing Technique | Good/<br>Roll-to-roll          | Fair/<br>Tape casting<br>then sintering | Good/<br>Roll-to-roll                                     |
| Companies                                      | Hydro Quebec,<br>Bolloré, Seeo | Ion Storage<br>System,<br>Quantumscape  | Toyota,<br>Samsung, Solid<br>Power,<br>PolyPlus           |



## Up Stream

- **Vulnerability:** Class I nickel, lithium, and cobalt are the primary supply chain vulnerabilities.
- **Vulnerability:** U.S. has a significant deficit in mineral refining and processing

## Mid Stream

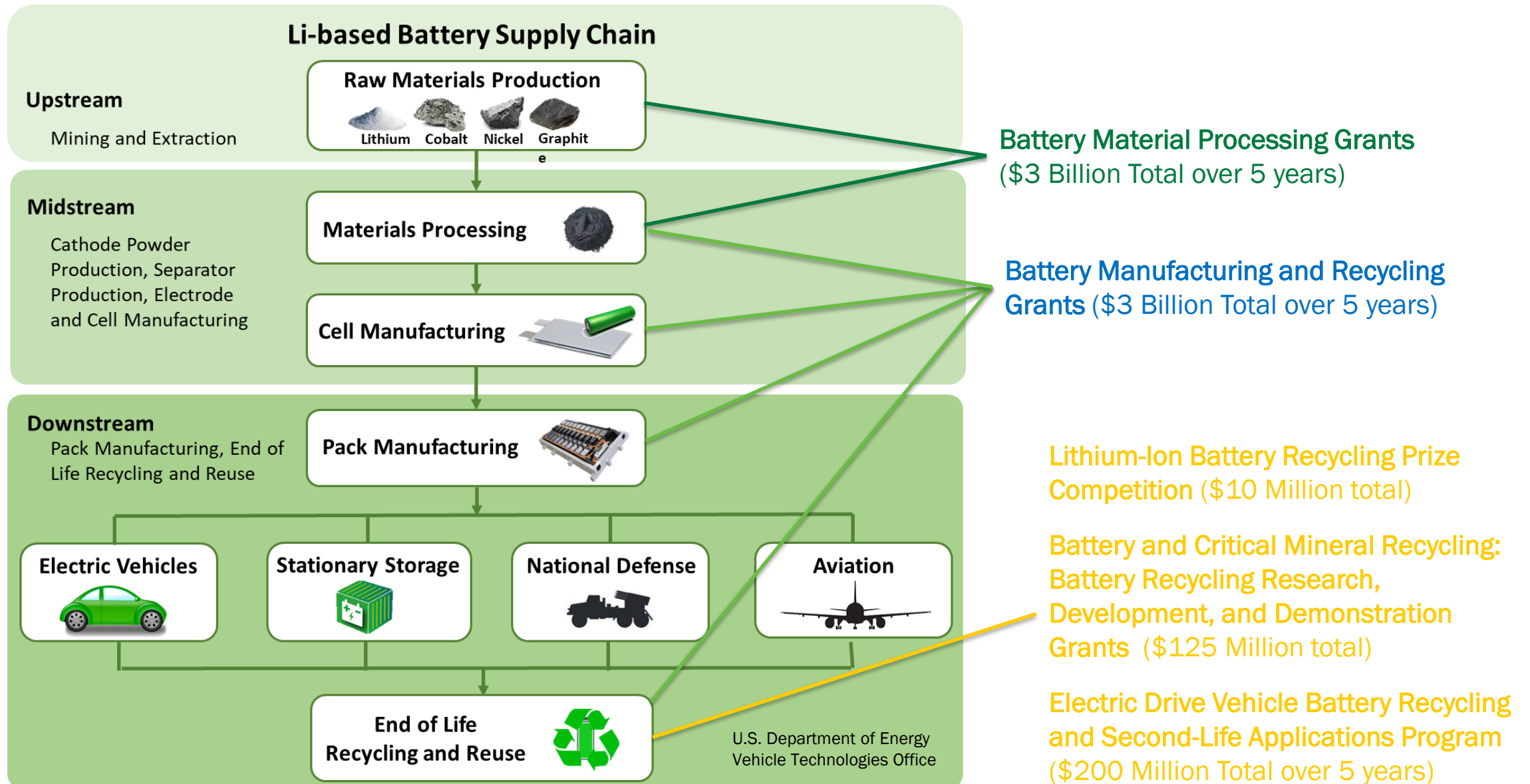
- **Vulnerability:** The U.S. has less than 10 percent of global market share for capacity across all major battery components and cell fabrication (with cathode and anode production capacity sorely lacking).

## Down Stream

- **Vulnerability:** U.S. lags other markets for domestic demand of lithium batteries, primarily driven by EV demand.
- **Vulnerability:** U.S. lags other markets in lithium battery recycling, with less than 5% of lithium-ion batteries recycled each year.



# Infrastructure Investment and Jobs Act



**Thank You**

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